Co-simulation of Mechanical and Hydraulic Systems of Shearer's Regulating System

Jie GAO[1], Haizhong ZHANG[2], Lirong WAN[3], Laihong REN[4], Liang WANG[*5]

College of Mechanical and Electronic Engineering, Shandong University of Science and Technology
579th, Qianwangang Road, Economic & Technical Development Zone, Qingdao, 266590, P.R.China

[1]imgj@ufl.edu; [2]zhanghaizhong092@163.com; [3]wanlr666@163.com; [4]renlaihong@126.com; [*5] wliang@sdust.edu.cn

Abstract

In order to study the dynamic characteristics of shearer's regulating system and to achieve position control of the shearer drum, the mechanical and hydraulic systems' models were established separately. The results show that a linear movement of the hydraulic cylinder will cause an impact force on the pin attached to the rocker arm. Meanwhile, the hydraulic model is nonlinear when the change of effective volume of the hydraulic cylinder is considered. Finally the co-simulation model of mechanical and hydraulic systems of shearer's regulating system was established. The simulation results show that the shearer drum's position can be controlled by the electro-hydraulic valve with the feedback of the rocker arm's angle.

Keywords

Shearer's Regulating System; Co-simulation; Mechanical System; Hydraulic System; Valve-controlled Asymmetric Cylinder

Introduction

The shearer is a typical equipment of complex mechanical, electrical and hydraulic systems, which is one of the key equipment for coal mining. The shearer's mechanical system and its hydraulic system are inseparable. The shearer arm is driven by the regulating hydraulic cylinder, while fluid pressure of the cylinder is changed by the shearer arm. In this paper, these two types of systems are linked together by means of co-simulation, to achieve state parameters transmission between them and to solve limitations of single-domain simulation.

Modelling of Shearer's Regulating Mechanical System

Shearer's regulating mechanical system is mainly consisted of hydraulic cylinder and rocker arm. The mechanical system can be abstracted to crank-rocker mechanism (Zhou J. X. and Zhang L., 2005) as shown in Fig. 1. The motion analysis method of mechanism is used to model the shearer's regulating mechanical system.

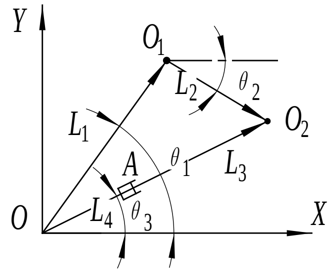

FIG. 1 SCHEMATIC OF SHEARER'S REGULATING MECHANICAL SYSTEM

From knowledge of mechanical principles, closed loop vector equation of the crank-rocker mechanism can be obtained. Equations decomposed in the horizontal direction and vertical direction are as follows:

$$\left.\begin{aligned} L_1\cos\theta_1 + L_2\cos\theta_2 &= (L_3+L_4)\cos\theta_3, \\ L_1\sin\theta_1 + L_2\sin\theta_2 &= (L_3+L_4)\sin\theta_3. \end{aligned}\right\} \tag{1}$$

The differential equation of Eq. (1) is as follow:

$$\begin{pmatrix} -L_2\sin\theta_2 & (L_3+L_4)\sin\theta_3 \\ L_2\cos\theta_2 & -(L_3+L_4)\cos\theta_3 \end{pmatrix}\begin{bmatrix}\omega_2 \\ \omega_3\end{bmatrix} = \begin{pmatrix} v_4\cos\theta_3 \\ v_4\sin\theta_3 \end{pmatrix}. \tag{2}$$

And the differential equation of Eq. (2) is:

$$\begin{pmatrix} -L_2\sin\theta_2 & (L_3+L_4)\sin\theta_3 \\ L_2\cos\theta_2 & -(L_3+L_4)\cos\theta_3 \end{pmatrix}\begin{bmatrix}\varepsilon_2 \\ \varepsilon_3\end{bmatrix} = \begin{pmatrix} a_4\cos\theta_3 - 2v_4\omega_3\sin\theta_3 + \omega_2^2 L_2\cos\theta_2 - \omega_3^2(L_3+L_4)\cos\theta_3 \\ a_4\sin\theta_3 + 2v_4\omega_3\cos\theta_3 + \omega_2^2 L_2\sin\theta_2 - \omega_3^2(L_3+L_4)\sin\theta_3 \end{pmatrix}. \tag{3}$$

Eq. (1), Eq. (2) and Eq. (3) describe the relationships between cylinder, piston and rocker arm in displacement, velocity and acceleration. By solving these equations above, motion characteristics of the mechanical system can be obtained.

The simulation block diagram of the mechanical system is shown in Fig. 2, which is calculating the kinematic characteristics of MG400/930-WD type shearer with Eq. (2). The simulation initial condition is the rocker arm and regulating cylinder in the same

horizontal position, where L_2=755mm, L_3=L_4=979mm, θ_2=-96.77° and θ_3=0. The velocity of cylinder piston is 100mm/s and simulation lasting time is 5s. The simulation result is shown in Fig. 3.

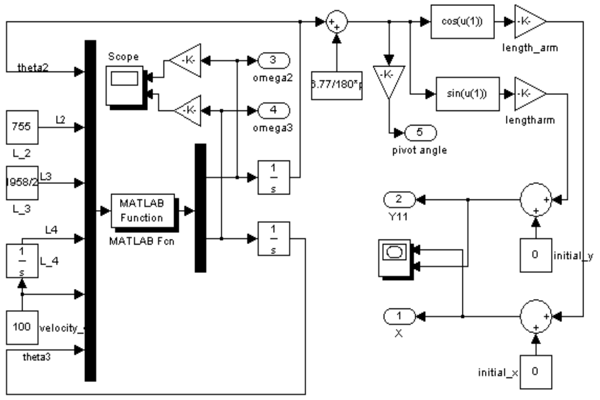

FIG. 2 BLOCK DIAGRAM OF SHEARER'S REGULATING SYSTEM

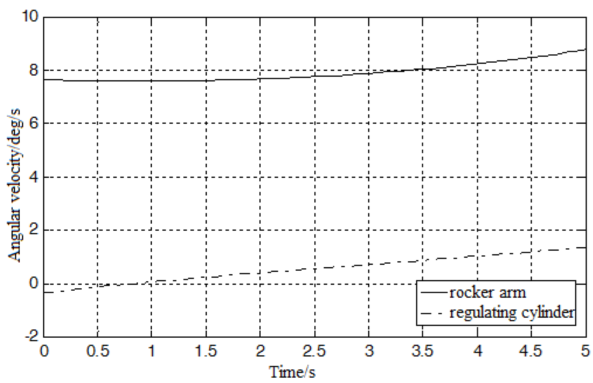

FIG. 3 ANGULAR VELOCITY OF ROCKER ARM AND CYLINDER

Fig. 3 shows that the angular velocity of the cylinder is approximately a slash, thus the force acting on the shearer's regulating system would be a constant. The angular velocity curve of rocker arm within the first 2s is relatively flat, but it gradually increases after 2s, indicating the rocker arm giving shock force to the entire adjusting system, during the process of shearer drum height adjusting.

Modelling of Valve-controlled Asymmetric Cylinder

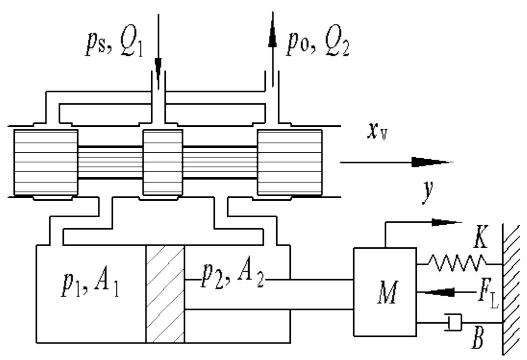

FIG.4 VALVE-CONTROLLED ASYMMETRIC CYLINDER

The principle of valve-controlled asymmetric cylinder is shown in Fig. 4. The spool valve is assumed to be an ideal zero opening four-port valve with four closure windows matching symmetrically. The inlet oil pressure p_s is a constant, and the outlet oil pressure p_0 is zero.

(1) Fluid continuity equation of hydraulic cylinder

For the none rod chamber, the equation is:

$$Q_1 - C_{ic}\left(p_1 - p_2\right) - C_{ec}p_1 = A_1\frac{dy}{dt} + \frac{V_1}{\beta_e}\frac{dp_1}{dt}. \tag{4}$$

For the rod chamber, there is:

$$C_{ic}\left(p_1 - p_2\right) - C_{ec}p_2 - Q_2 = -A_2\frac{dy}{dt} + \frac{V_2}{\beta_e}\frac{dp_2}{dt}. \tag{5}$$

The load pressure is defined as p_L=p_1-mp_2, and load flow is Q_L=(Q_1+mQ_2)/(1+m), where m=A_2/A_1<1 (Wang D. L., Li H. R. and Zhang J. C., 2003). In consideration of V_1=V_{10}+A_1y, V_2=V_{20}-A_2y, define V_{10}=V_{20}=V_0.

When the valve spool moves to the right, that is x_v>0, then we can get p_s=p_1+p_2/m^2. When it moves to the left, that is x_v<0, then we have p_s= m^2p_1+p_2.

Ignore internal leakage of the hydraulic cylinder, thus:

$$Q_L = A_1\frac{dy}{dt} + \frac{V_0}{\left(1+m^2\right)\beta_e}\frac{dp_L}{dt} + \frac{\left(1-m^2\right)A_1}{\left(1+m^3\right)\beta_e}y\frac{dp_L}{dt} + \frac{C_{ec}}{1+m^2}p_L. \tag{6}$$

(2) Force balanced equation of hydraulic cylinder and the load

$$A_1p_1 - A_2p_2 = A_1p_L = M\frac{d^2y}{dt} + B\frac{dy}{dt} + Ky + F_L. \tag{7}$$

(3) Pressure-flow linear equation of the valve

The general expression of the pressure-flow linear equation (Liang L. H., 2005) is as follow:

$$Q_L = K_qx_v - K_cp_L. \tag{8}$$

The block diagram of valve-controlled asymmetric cylinder is shown in Fig. 5.

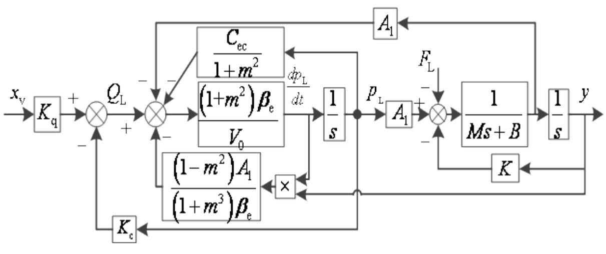

FIG. 5 BLOCK DIAGRAM OF VALVE-CONTROLED ASYMMETRIC CYLINDER

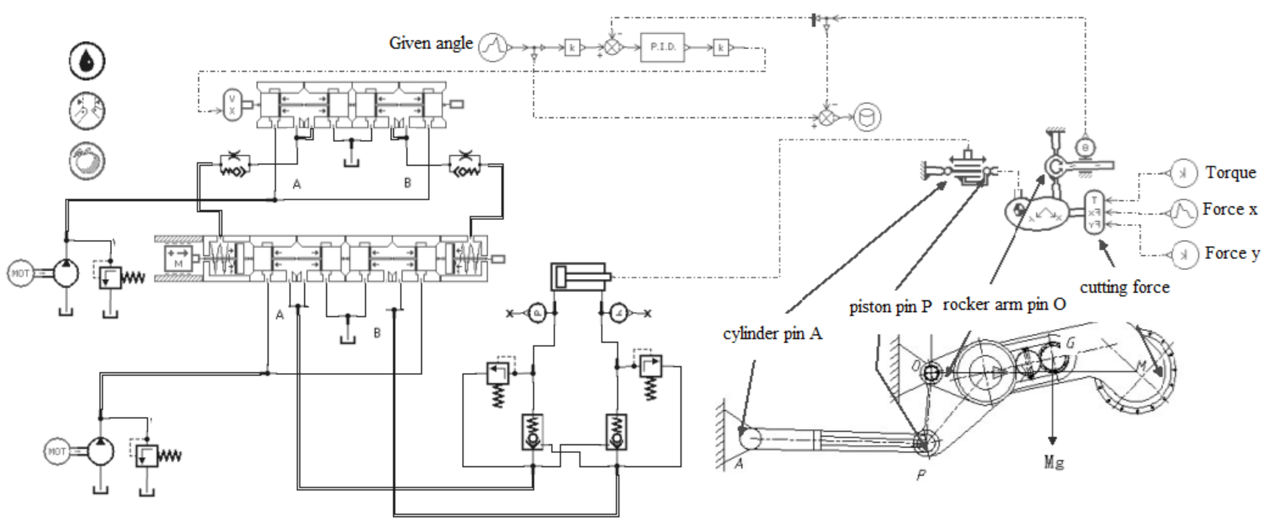

FIG. 6 CO-SIMULATION MODEL OF SHEARER'S REGULATING SYSTEM

Valve-controlled cylinder model in Fig. 5 is more general. It is no longer confined to the hypothesis of small displacement of the cylinder piston. From Eq. (6) or Fig. 5, there is a dp_L/dt, making the model no longer linear, which increases the analysis complexity. When it is ignored, this model is linear, but it is only applicable to the case of small displacement of cylinder piston.

Co-simulation of Mech-hydraulic of Shearer's Regulating System

To achieve co-simulation of shearer's regulating system, its mechanical system and hydraulic system need to be modelled first. The simulation model can be established using ADAMS (Zhao L. J. and Wang L., 2014) or AMESim (Chen X. Q., et al., 2012).

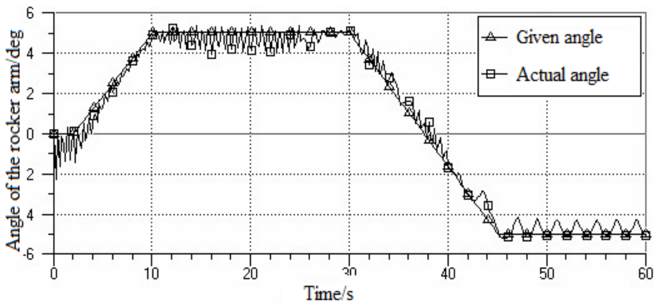

FIG. 7 COMPARISON OF ACTRUAL ANGLE AND GIVEN ANGLE OF THE ROCKER ARM

Co-simulation model of shearer's regulating system is shown in Fig. 6. The left part of Fig. 6 is the hydraulic system model which is modelled using Hydraulic and Hydraulic Component Design library of AMESim software. The right part of Fig. 6 is the mechanical system model built by Planar Mechanical library. Data transmission between these two systems is realized by the actuator module. The gravity of shearer drum and force of rocker arm cutting coal are taken into account. The rocker arm swing angle is real-timely collected by the angular displacement sensor and compared with the given angle. After the PID regulator, the compared error controls the displacement of valve spool, and ultimately controls the position of the shearer drum. To control the swing angle of the shearer rocker arm, the model simulation result is shown in Fig. 7.

In Fig. 7, at the early simulation stage, the rocker arm suddenly rotates to -2°. At this time there is no hydraulic oil in the regulating cylinder, namely the regulating force is zero. So the rocker arm swings downwards under gravity. With the continuous oil flowing from pump to cylinder, the rocker arm stopped swinging down. During the first 2s, due to the initial position of the rocker arm below the equilibrium position of it, the actual swing angle of it is always less than the given angle. Meanwhile, the curve is fluctuating, which is the result of interaction between mechanical inertia force and fluid pressure force. As the system damping is small, the rocker arm vibrates. During 2-10s, the rocker arm is controlled to swing upwards 5°, but its response lags behind the control objective. This is because the inertia of the shearer drum and rocker is huge and it is difficult to change its state of motion. Along with simulation time, the control error is reduced gradually. During 10-30s, the shearer drum is cutting top coal normally. Due to the change of drum cutting coal resistance, the rocker vibrates all the time. Meanwhile the center of shearer drum is below the control objective. During 30-45s, the rocker arm is going down. The cylinder piston rod is not only affected by the cutting force of shearer drum, but also affected by gravity of the shearer drum and rocker arm. In the 45-60s stage, the shearer is cutting

the bottom coal and the curve of rocker arm swing angle fluctuates above the given curve.

During the entire simulation process, the shearer rocker arm has always been affected by the dynamic load, which will cause shearer's vibration. So much attention should be payed when designing the shearer.

Conclusions

The shearer's regulating mechanical system model was established. By setting the initial condition, this model was tested using MATLAB to obtain angular velocity and acceleration of the shearer's regulating components. It can be used to analyze the kinematic performance during the drum lifting. Also the kinematic characteristics can be used for shearer's design and optimization.

The valve-controlled asymmetric nonlinear model of the shearer's regulating hydraulic system was established. The impact of large displacement of cylinder piston to the effective volume of the hydraulic cylinder is considered in this model, which will expand the scope of valve-controlled asymmetric cylinder model more widely.

To achieve the coupling of hydraulic system and mechanical system, the co-simulation model of mech-hydraulic of shearer's regulating system was established. The gravity of the rocker arm and shearer drum and the impact force of the drum cutting coal are taken into account. This model is closer to the actual working condition of shearer. The simulation results have guidance on the shearer's control, design and optimization. Also the modelling method is useful for reference of the same type of co-simulation.

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